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QUASI-BIENNIAL VARIATIONS IN THE "CENTERS OF ACTION"

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ABSTRACT

Quasi-biennial (about 28-mo) variations in surface pressure occur in the vicinity of the North Atlantic and North Pacific subtropical Highs and subpolar Lows, with harmonic amplitudes of order 0.4 mb. The subtropical Highs undergo quasi-biennial latitudinal and longitudinal oscillations averaging about 1° of latitude, with the Atlantic High apparently oscillating in the northeast-southwest direction and the Pacific High in the northwest-southeast direction. The quasi-biennial pressure oscillations in the North Atlantic subpolar Low and subtropical High are almost out of phase, implying a relatively strong quasi-biennial variation in surface zonal wind in North Atlantic temperate latitudes. There is evidence for a quasi-biennial variation in frequency of hurricanes and typhoons in the North Atlantic and North Pacific, and of severe storms in the vicinity of India. Within the quasi-biennial framework, an above-average frequency of hurricanes or typhoons is associated with above-average pressure in the respective subtropical Highs.

1. INTRODUCTION

Recent papers (Angell and Korshover, 1968; Brier, 1968) have presented evidence for a quasi-biennial variation in surface geostrophic wind in temperate latitudes of the Northern Hemisphere. This paper represents a preliminary effort to delineate those geographical areas where the quasi-biennial variations in surface pressure are most pronounced, and to indicate the extent to which these variations are due to displacements of the large-scale pressure systems. A possible association with the frequency of hurricanes and typhoons is indicated. A somewhat similar examination of surface temperature data was reported on in the work of Landsberg and others (1963). This latter reference also includes an extensive bibliography relating to quasi-biennial phenomena in general.

2. HARMONIC ANALYSIS OF STATION PRESSURE

An harmonic analysis procedure, previously discussed by Angell and others (1966), was applied to mean-monthly surface pressures at stations having long data records, with some emphasis on stations in the vicinity of the oceanic subtropical Highs in the Northern Hemisphere. Table 1 gives a listing of station latitude and longitude, as well as the length of record utilized (Smithsonian Institution, 1927, 1934, and 1947; U.S. Weather Bureau and Environmental Science Services Administration, 1959, 1965–1968; World Meteorological Organization, U.S. Weather Bureau, and Environmental Science Services Administration, 1961–1967). Figure 1 shows that at Bermuda, an island on the western edge of the North Atlantic subtropical High, the quasi-biennial oscillation in surface pressure is quite apparent, with an harmonic amplitude (one-half the range) of nearly 0.3 mb based on 100 yr of mean-monthly data. In this, and subsequent diagrams of a similar nature, the quasi-biennial period (in months) of maximum harmonic amplitude is indicated above the peak, while for comparison the annual (top) and semiannual harmonic amplitudes of the surface pressure are indicated in the upper right-hand corner of the diagram. Thus, at Bermuda the 27.6-mo variation in surface pressure exceeds one-half the annual variation and one-fifth the semiannual variation.

Figure 2 shows harmonic analyses of surface pressure at other stations on the periphery of the North Atlantic. Note especially the 28.3-mo oscillation in Iceland (0.6-mb amplitude) and the 28.2-mo oscillation at Washington, D.C. (0.2-mb amplitude). The former station suggests that subpolar Lows as well as subtropical Highs exhibit a relatively strong quasi-biennial oscillation, and this will be examined in more detail in the next section. It is interesting that at Washington, D.C., the semiannual oscillation in surface pressure is anomalously low while at Bermuda, only 1500 km distant, it is anomalously high. The quasi-biennial pressure oscillation in the Azores is not as impressive as at Bermuda due to a secondary peak near 40 mo.

With regard to the other stations listed in table 1, quasi-biennial oscillations in surface pressure are barely

TABLE 1.—*Stations utilized for the harmonic analysis of mean-monthly surface pressure*

Station	Latitude	Longitude	Years of record
Akureyri, Iceland	66° N.	18° W.	1874–1967
Juneau, Alaska	58° N.	135° W.	1917–1967
Edinburgh, Scotland	56° N.	3° W.	1777–1967
Washington, D.C	39° N.	77° W.	1873–1967
St. Louis, Mo	39° N.	90° W.	1873–1967
Ponta Delgada, Azores	38° N.	26° W.	1894–1967
San Francisco, Calif	38° N.	122° W.	1873–1967
Kagoshima, Japan	34° N.	131° E.	1883–1967
Hamilton, Bermuda	32° N.	65° W.	1866–1967
Honolulu, Hawaii	21° N.	158° W.	1891–1967
San Juan, Puerto Rico	18° N.	66° W.	1899–1967
Cristobal, Canal Zone	9° N.	80° W.	1908–1967
Zanderij, Surinam	5° N.	55° W.	1919–1967
Fanning Island	4° N.	159° W.	1922–1967
Juan Fernández Island	34° S.	79° W.	1911–1967

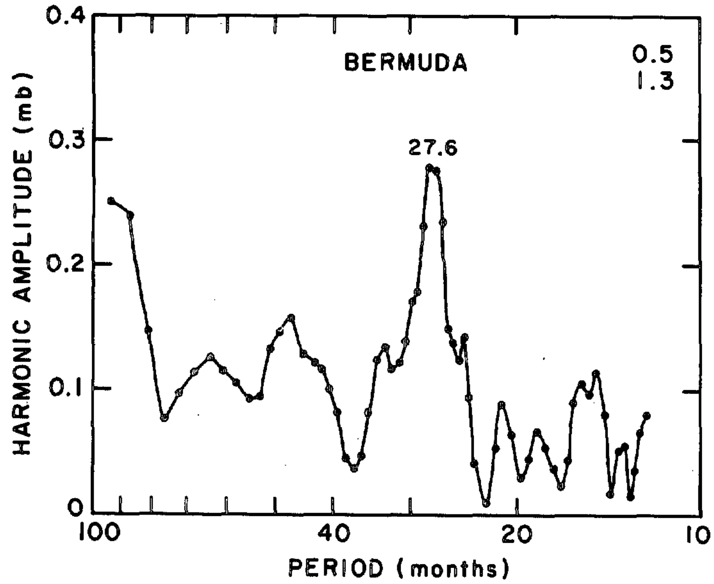

FIGURE 1.—Harmonic amplitude of Bermuda mean-monthly surface pressure as a function of period of oscillation. The number above the peak in the trace indicates the dominant quasi-biennial period of oscillation in months. The two numbers in the upper right-hand corner represent the harmonic amplitudes (in millibars) of the annual (top) and semiannual oscillations in surface pressure at the station.

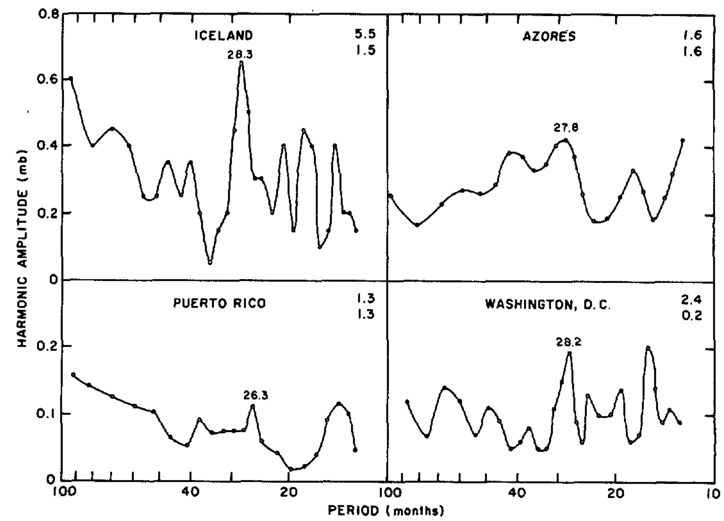

FIGURE 2.—Same as figure 1 for other stations on the periphery of the North Atlantic. Note the change in ordinate scale.

discernible at Hawaii and Juan Fernández Island, while a 25.1-mo oscillation at Fanning Island resembles the 26.3-mo oscillation at Puerto Rico (fig. 2). There is no evidence for quasi-biennial variations in surface pressure at Edinburgh, Scotland (for either of the two 100-yr periods); St. Louis, Mo.; Cristobal, Canal Zone; Zanderij, Surinam; Juneau, Alaska; San Francisco, Calif.; or Kagoshima, Japan.

3. HARMONIC ANALYSIS OF PRESSURE, LATITUDE, AND LONGITUDE OF THE "CENTERS OF ACTION"

The station data presented in the previous section suggest that the quasi-biennial oscillation in surface pressure is most pronounced in the vicinity of the Azores-Bermuda High and the Icelandic Low. However, from data at a fixed geographical location it is not possible to tell whether the periodicity is brought about by an overall increase or decrease of pressure or by movement of the pressure system with little change in central pressure. In order to examine this aspect, mean-monthly pressures at 5° latitude-longitude intervals (obtained with the aid of a computer from the daily Historical Weather Map Series of the U.S. Weather Bureau, 1899–1939) were used to estimate mean-monthly pressures in the centers of North Atlantic and Pacific subtropical Highs and subpolar Lows, as well as the mean-monthly latitudes and longitudes of these centers. The latter values were obtained at 5° latitude-longitude intervals except when two grid points had the same pressure, in which case an interpolation was applied. Such a coarse readout undoubtedly results in a conservative estimate of the displacement of the subtropical Highs and subpolar Lows. These data were then subjected to the same harmonic analysis procedure used previously. Since mean-monthly compilations of surface pressure during World War II are still not available, it was necessary to perform the harmonic analysis separately for the years 1899–1939 and 1945–1967, and then to average the amplitudes of the harmonics by the 2:1 ratio approximating the respective lengths of record. This is believed to be a reasonable procedure.

Figure 3 shows the average harmonic analyses so obtained. The quasi-biennial variation in maximum surface pressure in this moving coordinate system is about twice as large in the North Atlantic subtropical High (0.4 mb) as in the North Pacific subtropical High, and a similar ratio applies to the minimum surface pressure in the Atlantic subpolar Low (0.6-mb amplitude) and Pacific subpolar Low. Accordingly, the quasi-biennial variation in surface zonal wind should be more pronounced in North Atlantic than in North Pacific temperate latitudes, and this is considered further in the next section. The point to be emphasized, however, is that all four "centers of action" exhibit a quasi-biennial (27.5- to 28.4-mo) variation in central pressure of magnitude 0.2 to 0.6 mb. It is this similarity in period that implies significance, not the individual peak values themselves.

Because of the similarity in quasi-biennial pressure amplitude at the centers of the subtropical Highs and subpolar Lows, and at nearby fixed stations, it would appear that most of the quasi-biennial surface pressure variation at these stations is due to an overall increase or decrease of pressure rather than to movement of the pressure systems. Nevertheless, despite the coarse 5° latitude-longitude grid utilized, there *is* evidence for a quasi-

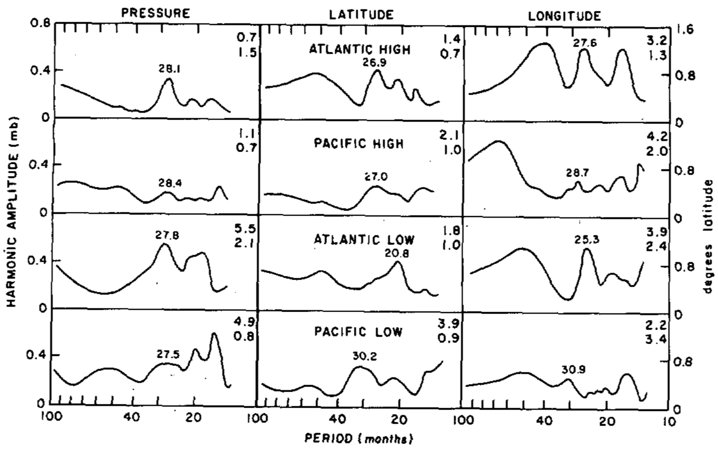

FIGURE 3.—Harmonic amplitude of mean-monthly surface pressure, latitude, and longitude at the centers of North Atlantic and Pacific subtropical Highs and subpolar Lows. The scale (in degrees latitude) for latitudinal and longitudinal displacements of the high and low centers is given along the right-hand ordinate. Otherwise, see legend for figure 1.

TABLE 2.—*Phase differences (in months) among times of surface pressure, latitude, and longitude maxima for quasi-biennial (25- to 30-mo) oscillations in North Atlantic and North Pacific subtropical Highs and subpolar Lows. The evaluations are carried out separately for the years 1899–1939 and 1945–1967, and averaged by a 2 : 1 weighting factor.*

	Pressure minus latitude	Longitude minus latitude
Atlantic subtropical High		
1899–1939	5.7	12.9
1945–1967	0.3	15.4
Average	3.9	13.7
Pacific subtropical High		
1899–1939	3.3	−1.2
1945–1967	10.1	4.2
Average	5.6	0.6
Atlantic subpolar Low		
1899–1939	−9.0	1.8
1945–1967	0	−3.5
Average	−6.0	0
Pacific subpolar Low		
1899–1939	5.3	−8.2
1945–1967	3.5	−17.0
Average	4.7	−11.1

biennial (26.9- to 28.7-mo) variation in latitude and longitude of the North Atlantic and Pacific subtropical Highs of magnitude 0.6° to 1.2° of latitude, as shown by the right-hand diagrams of figure 3. Quasi-biennial latitude and longitude variations are not so obvious in the case of the subpolar Lows, with highly variable dominant periodicities of 20.8, 25.3, 30.2, and 30.9 mo.

4. INTERRELATION AMONG PRESSURE, LATITUDE, AND LONGITUDE OF THE "CENTERS OF ACTION"

The phase information available from the harmonic analysis has been averaged over the period interval 25 to 30 mo for the subtropical Highs and subpolar Lows, even though quasi-biennial oscillations in latitude and longitude are not obvious in the latter cases. The previously cited evidence for a 28-mo periodicity in surface pressure is supported by the observation that the prewar data sample yields a quasi-biennial pressure maximum in the North Atlantic subtropical High on Mar. 27, 1940, whereas the postwar sample yields a pressure maximum on Mar. 27, 1947, or within 6 days of three (28-mo) cycles later. In the case of the North Atlantic subpolar Low, the respective dates are May 3, 1939, and May 18, 1946, or within 12 days of three (28-mo) cycles later. Results are nearly as good for the North Pacific subtropical High and subpolar Low.

Table 2 shows the phase difference in months between the time of maximum pressure and maximum latitude and the time of maximum latitude and maximum longitude for quasi-biennial variations in each of the four centers of action. The significance of these phase differences is not easy to determine. Certainly, one necessary attribute for significance is consistency in phase difference between pre- and post-World War II periods. Table 2 shows such a consistency in most cases, with a tendency for the quasi-biennial oscillations in latitude and longitude to be in phase in the case of the Pacific subtropical High and the Atlantic subpolar Low, and out of phase in the case of the Atlantic subtropical High and the Pacific subpolar Low. This is shown schematically in figure 4 by the arrows, where the top of the diagram represents north. Note the alleged symmetry in quasi-biennial displacement, with the Pacific Low and Atlantic High undergoing essentially a northeast-southwest oscillation and the Atlantic Low and Pacific High a northwest-southeast oscillation. The circles in figure 4 indicate the time of quasi-biennial pressure maximum and minimum relative to the displacement of each center of action, as obtained from table 2. The quasi-biennial surface-pressure maximum appears to occur after the time of quasi-biennial latitude maximum except in the case of the Atlantic Low. It is emphasized that, since the quasi-biennial period of oscillation is about 28 mo, these variations in pressure, latitude, and longitude are not fixed seasonally.

It is also of interest to determine the quasi-biennial interactions *among* the centers of action, that is, what is their phase relationship to one another at any given time? As shown by table 3, within the period interval 25–30 mo, the phase differences in time of pressure maximum among the centers of action are very consistent for prewar and postwar periods. This consistency obviously does not extend to the adjacent period bands of 20–25 and 30–35 mo. This suggests that the quasi-biennial oscillations *are* of special significance and enhances our confidence in the representativeness of the phase relationships.

The crosses in figure 4 indicate the stages of the quasi-biennial oscillations in the North Atlantic subpolar Low and the North Pacific subtropical High and subpolar Low at the time of quasi-biennial pressure maximum in the North Atlantic subtropical High. For example, at the time

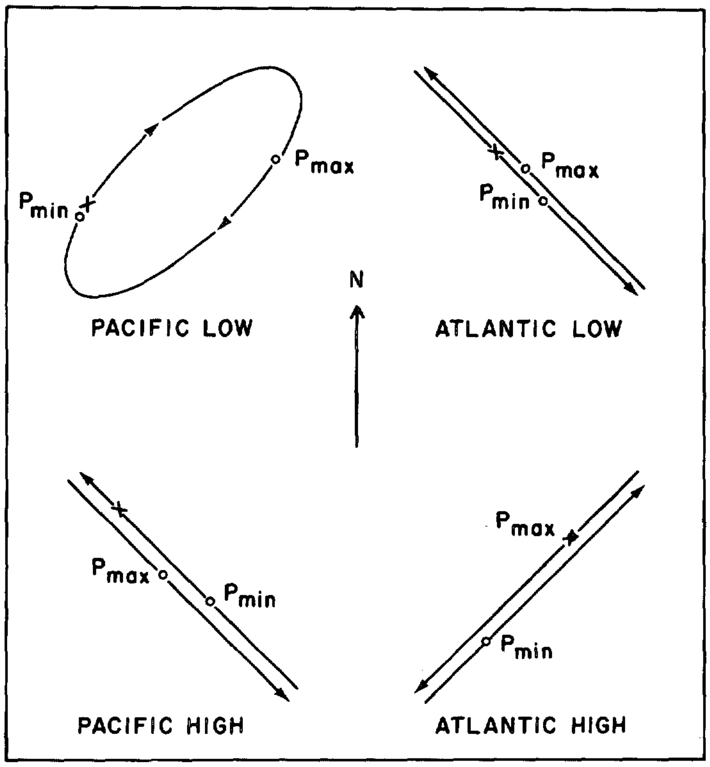

FIGURE 4.—Schematic representation of the apparent quasi-biennial displacements of North Atlantic and Pacific subtropical Highs and subpolar Lows. The central arrow points toward the North Pole. The circles indicate the times of quasi-biennial pressure maxima and minima relative to the quasi-biennial latitudinal and longitudinal displacements of each High and Low separately. The crosses indicate the stages of the quasi-biennial oscillations in the other Highs and Lows relative to the time of pressure maximum in the Atlantic subtropical High, and thus serve to tie together the four separate quasi-biennial oscillations.

TABLE 3.—*Phase differences (in months) among times of surface-pressure maxima for quasi-biennial (25- to 30-mo) oscillations of the four centers of action, as well as for oscillations of 20–25 and 30–35 mo. The time of pressure maximum in the Atlantic subtropical High is taken as the standard, with a positive (negative) value indicating the pressure maximum in this High occurs a given number of months before (after) the pressure maximum in the other centers. The evaluations are carried out separately for the years 1899–1939 and 1945–1967, and averaged by a 2 : 1 weighting factor.*

	Period interval (months)		
	20–25	25–30	30–35
Pacific subtropical High			
1899–1939	1.2	7.3	−1.7
1945–1967	−5.0	8.1	−13.4
Average	−0.9	7.8	−5.6
Atlantic subpolar Low			
1899–1939	−3.2	−10.8	3.9
1945–1967	11.2	−10.1	−0.6
Average	1.6	−10.6	2.4
Pacific subpolar Low			
1899–1939	12.4	10.6	5.6
1945–1967	8.1	14.3	0.0
Average	11.0	11.8	3.7

of quasi-biennial pressure maximum in the North Atlantic subtropical High, the pressure in the North Atlantic subpolar Low is approaching its quasi-biennial minimum. Thus, the quasi-biennial surface zonal wind oscillation in North Atlantic temperate latitudes should be relatively large, not only because of the relatively large quasi-biennial pressure oscillations in the North Atlantic (fig. 3) but also because the quasi-biennial pressure oscillations in the subtropical High and subpolar Low are almost out of phase. In the North Pacific, on the other hand, the quasi-biennial pressure oscillations in the subtropical High and subpolar Low are indicated to be only 90° out of phase, so that a smaller quasi-biennial zonal wind oscillation would be expected for this reason as well as because of the smaller amplitude of the quasi-biennial pressure oscillation. Note that, according to the evidence presented here, the North Atlantic subpolar Low and subtropical High tend to move northward and southward in phase but eastward and westward out of phase, whereas the Atlantic and Pacific subpolar Lows tend to move eastward and westward in phase but northward and southward out of phase while in the quasi-biennial mode. Finally, it might be pointed out that at the time indicated by the crosses in figure 4 the centers of action appear to be moving clockwise around North America when consideration is given only to displacements of quasi-biennial period.

5. EVIDENCE FOR QUASI-BIENNIAL VARIATIONS IN TYPHOON AND HURRICANE FREQUENCY

The question arises as to whether the quasi-biennial variations in pressure and location of the subtropical Highs are associated with a quasi-biennial variation in hurricane and typhoon frequency. To the writers' knowledge, there is no *published* evidence of a quasi-biennial variation in either hurricane or typhoon frequency. The detection of such a periodicity is made difficult by the nonuniform frequency of the phenomenon, that is, as is well known, most hurricanes and typhoons occur during only a few months in late summer and early fall. Figure 5 shows the results of the harmonic analysis for North Pacific typhoons (1884–1967), North Atlantic hurricanes (1886–1967), severe storms (winds exceeding 25 m sec^{-1}) in the vicinity of India (1877–1966), and the total of all three. The mean-monthly typhoon frequency was obtained from Chin (1958) and Anonymous (1968), hurricane frequency from DeAngelis (1967), and Indian severe storm frequency from Anonymous (1964). A maximum in harmonic amplitude consistently occurs near periods of 28 mo and 21 mo for the individual storm types, with the harmonic amplitude at these periods averaging somewhat more than one-tenth the annual amplitude. When the typhoons, hurricanes, and Indian severe storms are summed by month, and the harmonic analysis performed on that sum, a dominant periodicity of 26.3 mo is delineated.

Because of the danger that the harmonic analysis in the quasi-biennial wave band is contaminated by the relatively large annual oscillation, and because of the uncertainty in applying harmonic analysis to a data series possessing cyclically repetitive zero values, an alternate analysis

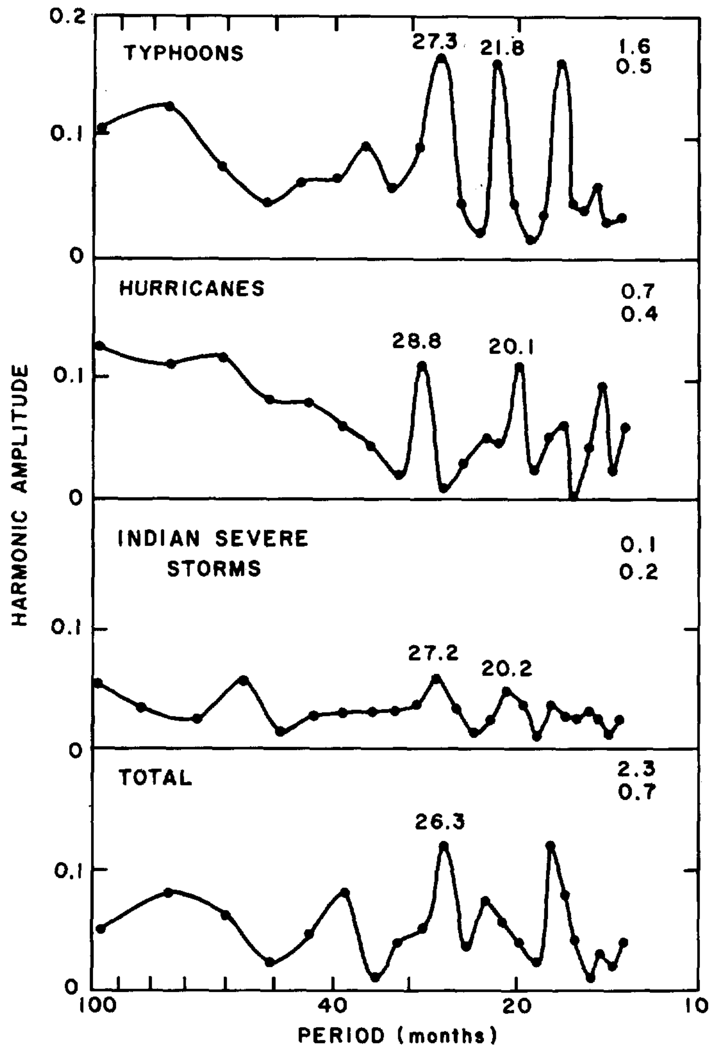

FIGURE 5.—Harmonic amplitude of mean-monthly frequency of North Pacific typhoons, North Atlantic hurricanes, severe storms (winds greater than 25 m sec^{-1}) in the vicinity of India, and the total of all three. Otherwise, see legend for figure 1.

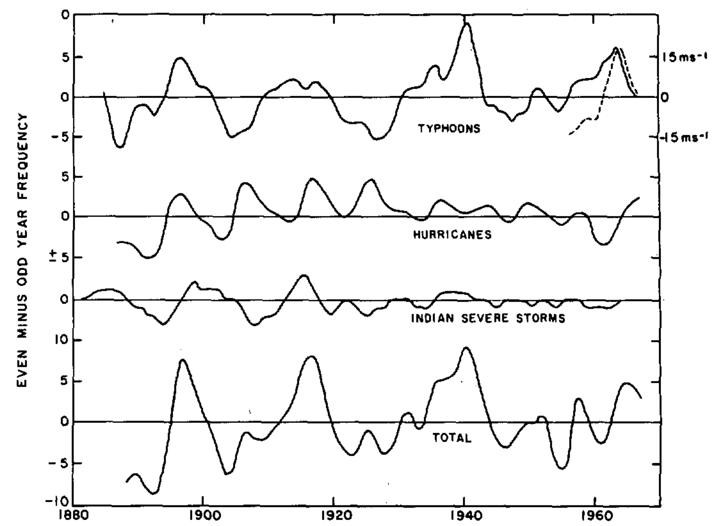

FIGURE 6.—Even-minus-odd-year difference in frequency of North Pacific typhoons, North Atlantic hurricanes, severe storms in the vicinity of India, and the total of all three. The dashed line in the upper right-hand corner gives the even-minus-odd-year difference in 50-mb zonal wind (m sec^{-1}) at Majuro (7° N., 121° E.) during the typhoon season, with positive values indicating a stronger west wind during the even-numbered years.

technique was deemed desirable. The even-minus-odd-year difference method (Angell and Korshover, 1968) is particularly applicable to data of this type. In this method, the number of hurricanes or typhoons in the odd-numbered years is subtracted, year by year, from the number in the even-numbered years, and these first differences are then smoothed through the determination of 3-yr running averages.

The top trace in figure 6 shows the even-minus-odd-year frequency of North Pacific typhoons obtained in this manner. A periodicity is apparent, with the number of typhoons in even-numbered years generally exceeding those in odd-numbered years during 1894–1901, 1910–1920, 1930–1943, and 1956–1966. The pronounced even-year maximum around 1940 may be partly the result of a sudden improvement in observational capability just before the start of the Pacific phase of World War II. The correlogram based on these data yields a 22-yr periodicity, and since a maximum in typhoon frequency in, for example, August of an even-numbered year would again occur in August of an even-numbered year after 22 yr if there exists an underlying periodicity of 26.5 or 22.0 mo, this technique yields nearly the same result as the harmonic analysis. Between 1900 and 1960, North Atlantic hurricanes were most frequent during even-numbered years, with evidence that this trend was reversed before 1900 and is now reversing again. The regular 10-yr fluctuation in even-minus-odd-year hurricane frequency before 1930 implies a 30- or 20-mo underlying periodicity, again in good agreement with the harmonic analysis. The Indian severe storms exhibit a trend similar to that of the typhoons prior to 1920 (generally compatible with the harmonic analysis), but thereafter the periodicity disappears. If the number of typhoons, hurricanes, and severe storms is summed, and the even-minus-odd-year differences evaluated (bottom trace of fig. 6), there is quite pronounced evidence for a quasi-biennial periodicity in severe storms all around the Northern Hemisphere (in agreement with the harmonic analysis), with some breakdown around 1960 due to the recent out-of-phase relation between typhoons and hurricanes.

In summary, both harmonic analysis and the even-minus-odd-year difference technique provide evidence for a quasi-biennial (about 28-mo) variation in frequency of typhoons, hurricanes, and Indian severe storms. The data also suggest the existence of a 21-mo periodicity in these storms. The significance of the latter periodicity is not apparent.

Comparison of the dates of quasi-biennial (assumed 28-mo) hurricane and typhoon maxima with the dates of quasi-biennial pressure maxima in the subtropical Highs indicates that, on the average, hurricane frequency is a maximum 0.6 mo after the pressure maximum in the North Atlantic subtropical High and typhoon frequency is a maximum 3.9 mo after the pressure maximum in the North Pacific subtropical High (quasi-biennial hurricane and typhoon periodicities out of phase on the average). Reference to figure 4 shows that, within the quasi-biennial framework then, hurricane frequency is a maximum when the North Atlantic subtropical High is moving southwestward and typhoon frequency is a maximum when the North Pacific subtropical High is nearing the end of its movement southeastward. An inphase relation between subtropical high pressure and storm frequency is supported by the correlation of 0.35 (significant at the 5 percent level according to the Fisher test) between even-minus-odd-year difference in surface pressure in the North Pacific subtropical High and even-minus-odd-year difference in typhoon frequency.

Thus far we have made no attempt to relate quasi-biennial surface pressure fluctuations or quasi-biennial variations in frequency of severe storms to the well-known quasi-biennial zonal wind and temperature oscillations in the equatorial stratosphere. At least in the latter case, such a comparison might conceivably be of practical use. With the assumption of a 28-mo periodicity in typhoon and hurricane frequency, typhoon frequency is above average (hurricane frequency below average) when the wind in the low stratosphere (say 50 mb) is westerly. Support for this finding is obtained from the even-minus-odd-year difference technique. The dashed line in the upper right-hand corner of figure 6 shows the even-minus-odd-year difference in 50-mb wind at Majuro (7° N., 171° E.) during the typhoon season, June through October. The similarity in trend of the dashed and solid curve indicates an inphase relation between typhoon frequency and west wind. However, these results are not conclusive, and in any event the large quasi-biennial period of oscillation (nearly 34 mo) during the past few years is beginning to confuse the relation.

6. SUMMARY

There exists a quasi-biennial (about 28-mo) variation in mean-monthly surface pressure in the vicinity of the North Atlantic and North Pacific subtropical Highs and subpolar Lows, with the oscillation particularly pronounced in the North Atlantic where the harmonic amplitude attains 0.4 mb in the Azores-Bermuda High and 0.6 mb in the Icelandic Low. The mean-monthly latitudes and longitudes of the centers of the North Atlantic and North Pacific subtropical Highs exhibit a similar periodicity, with harmonic amplitudes of about 1° of latitude in the former case. It is noted that the period of pressure oscillation at the surface is at least 1 mo longer than the 26- to 27-mo wind and temperature periodicity observed (until recently) in the low equatorial stratosphere.

Examination of the harmonic phases suggests that the North Atlantic subtropical High oscillates in a northeast-southwest direction with the quasi-biennial period, whereas the Pacific subtropical High oscillates in a northwest-southeast direction with this period. In both cases, the quasi-biennial pressure maximum occurs a few months after the quasi-biennial latitude maximum. The quasi-biennial pressure variations in the Azores-Bermuda High and Icelandic Low are nearly out of phase, helping to intensify the quasi-biennial surface zonal wind oscillation in North Atlantic temperate latitudes.

Harmonic analysis and the even-minus-odd-year differencing technique provide evidence for a quasi-biennial variation in hurricane and typhoon frequency in the North Atlantic and North Pacific and in the frequency of severe storms in the vicinity of India, with a tendency for hurricane and typhoon frequency to be above average when, within the quasi-biennial framework, the respective subtropical Highs are of above-average intensity. There is also a suggestion that typhoon frequency is above average when the winds in the low equatorial stratosphere are westerly.

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